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## Duty-Cycle and On-Time Measurement Using Power Supplies

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## **Duty-Cycle and On-Time Measurement Using Power Supplies**

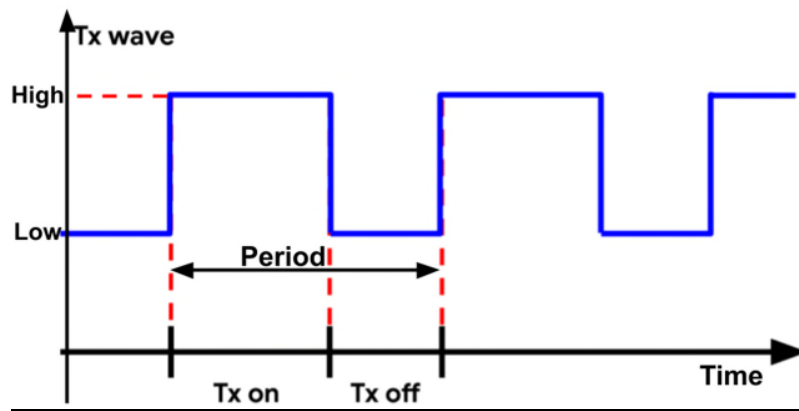
### **ABSTRACT**

The duty cycle and the on-time of transmitters are typically measured using digital oscilloscopes or spectrum analyzers, which both require substantial effort and training to configure and operate. The use of this equipment is also subject to some human error, since their readings depend on the positions of markers set on their screens by a human operator. This disclosure describes techniques that leverage the ability of a power supply to sample a current supplied by it to a device under test (DUT) to determine the duty cycle and the on-time of the DUT. The techniques of this disclosure achieve, across a broad range of scenarios, accurate measurements of duty-cycle and transmitter on-time. The cost of the measurement apparatus is significantly lower than the cost of conventional measurement equipment such as digital oscilloscopes or spectrum analyzers.

### **KEYWORDS**

- Duty cycle
- Transmitter on-time
- Test and measurement
- Power Supply
- Digital oscilloscope
- Spectrum analyzer

## BACKGROUND



**Fig. 1: Defining duty cycle and transmitter on-time**

Fig. 1 illustrates a voltage or current waveform at a point within a WiFi transmitter or other electronic device. The period of the waveform is the time for the waveform to complete one full cycle. The time within a period during which the transmitter is on, e.g., when the current and power consumption is high, is known as transmitter on-time (Tx on). The time within a period during which the transmitter is off, e.g., when the current and power consumption is low, is known as transmitter off-time (Tx off). Duty cycle is the fraction of the period in which the transmitter is on:

$$\text{Duty cycle} = \frac{\text{Tx on}}{\text{Tx on} + \text{Tx off}}.$$

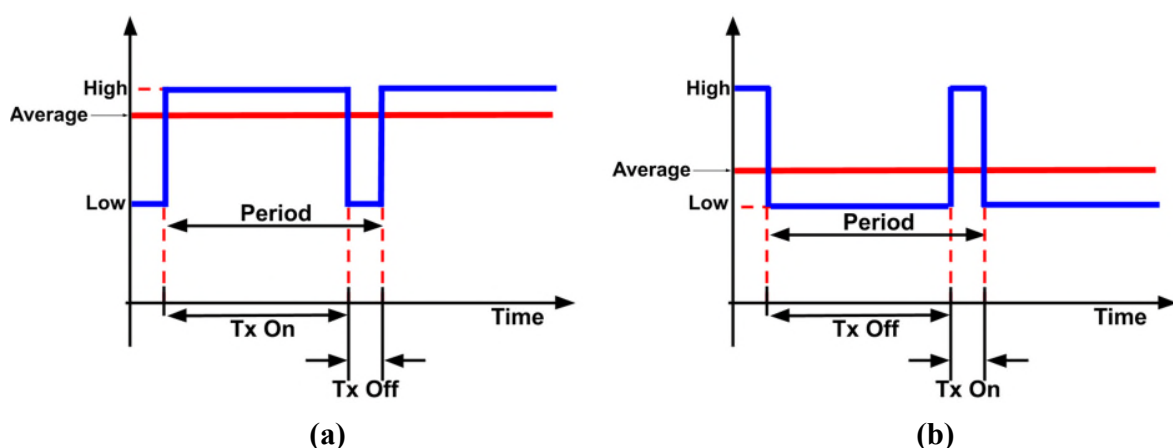
For various reasons, e.g., to check loading conditions, to debug, etc., it is of interest to measure the duty cycle and the on-time of electronic devices. For example, the duty cycle of a WiFi transmitter, which is the fraction of time the transmitter is transmitting packets, is correlated to such parameters of interest such as the modulation and coding rate of transmission, packet length, interval between packets, etc.

The duty cycle and transmitter on-time are typically measured using digital oscilloscopes (for baseband signals) and spectrum analyzers (for radio-frequency signals), both of which are quite expensive, in the range of ten-to-fifty thousand dollars. Further, an oscilloscope and a spectrum analyzer both require substantial effort and training to configure and operate. These are also subject to some human imprecision, since their readings depend on the positions of markers set on their screens by a human operator.

The power supply is a piece of laboratory equipment that supplies power to an electronic device. It is ten-to-twenty percent of the cost of the oscilloscope or a spectral analyzer and can measure the current that it supplies to the electronic device at a moderate resolution, e.g., twenty microseconds or thereabouts.

## DESCRIPTION

This disclosure describes techniques that leverage the ability of a power supply to sample a current supplied by it to a device under test (DUT) to determine the duty cycle and the on-time of the DUT.



**Fig. 2: The average current drawn from a power source is related to the duty cycle: (a) If the duty cycle is high (close to 100%), the average current is close to the high current; (b) If the duty cycle is low (close to 0%), the average current is close to the low current.**

Fig. 2 illustrates the relationship between the average current and the duty cycle. If the duty cycle is high (Fig. 2(a), close to 100%), the average current is close to the high current. If the duty cycle is low (Fig. 2(b), close to 0%), the average current is close to the low current. In general, the average current is related to the duty cycle and the low and high currents by the following equation.

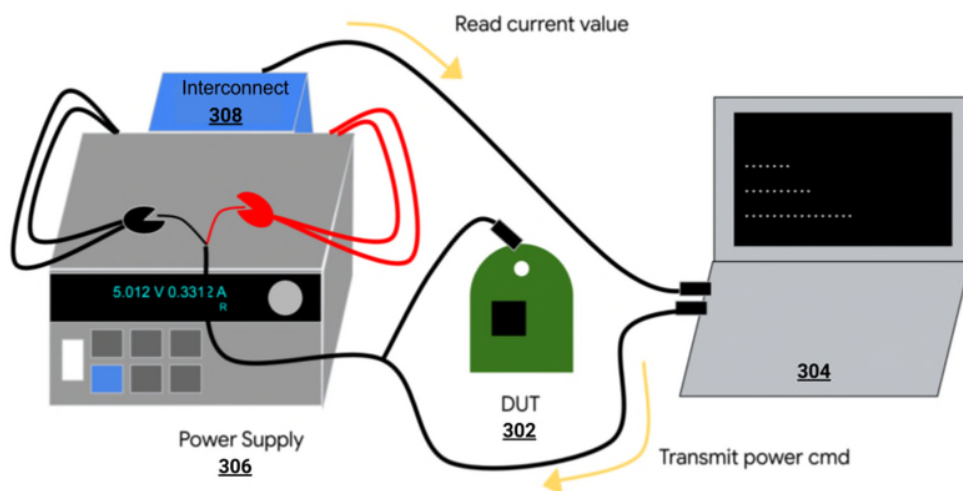
Average current = Duty cycle  $\times$  High current + (1 – Duty cycle)  $\times$  Low current.

Rearranging the above equation, the duty cycle can be written in terms of the low, high, and average currents as follows.

$$\text{Duty cycle} = \frac{\text{Average current} - \text{Low current}}{\text{High current} - \text{Low current}} \quad (1)$$

The techniques of this disclosure compute the duty cycle of a device under test (DUT) by measuring the low, high, and average currents supplied to the DUT by a power supply, and by plugging in the measured currents into equation (1).

#### Laboratory set-up

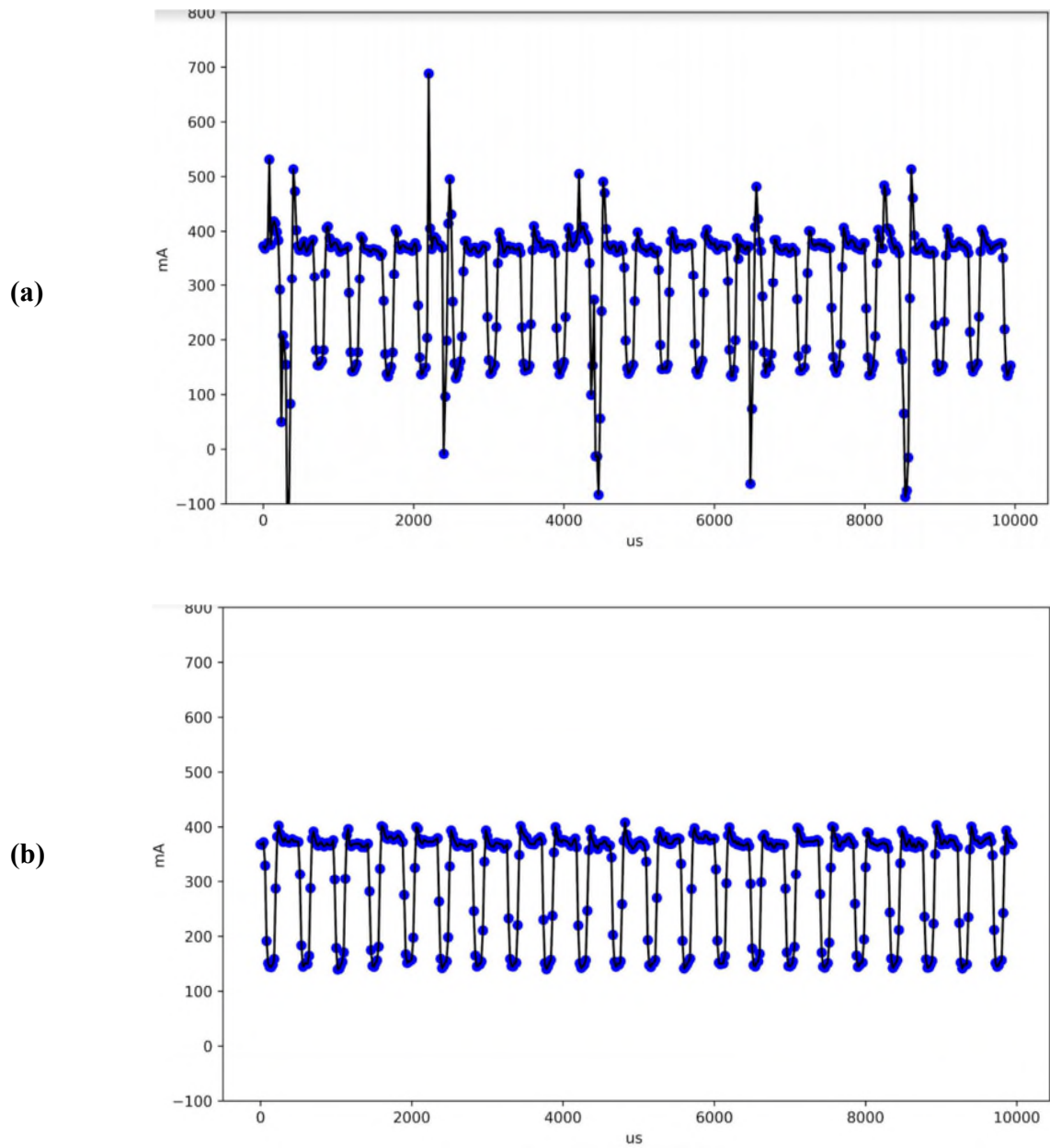


**Fig. 3: Laboratory setup**

Fig. 3 illustrates a laboratory setup for the purposes of measuring the duty cycle and the transmitter on-time. A computer (304) controls a device under test (DUT, 302) and a power supply (306) via an interconnect (308). The power supply provides power to the DUT and is capable of sampling the current supplied by it. The power supply transmits its current samples to the computer in the form of a time series. The DUT can be, e.g., a WiFi transmitter. The interconnect can be, e.g., a universal serial bus (USB) interface, a general-purpose interface bus (GPIB), etc.

An operator sends a command to the DUT to start operation, e.g., transmission at a certain bit-rate, packet-length, inter-packet interval, modulation, code, etc. The power supply samples its current and sends it to the computer.

Fig. 4 illustrates example current waveforms captured by the power supply. The blue circles are current samples. The raw current waveforms (Fig. 4(a)) can exhibit positive or negative peaks at transitions. The peaks are due to excess current compensation by the power supply and, as such, are artifacts. The raw current waveforms are processed to remove peaks, resulting in an artifact-free current waveform (Fig. 4(b)).

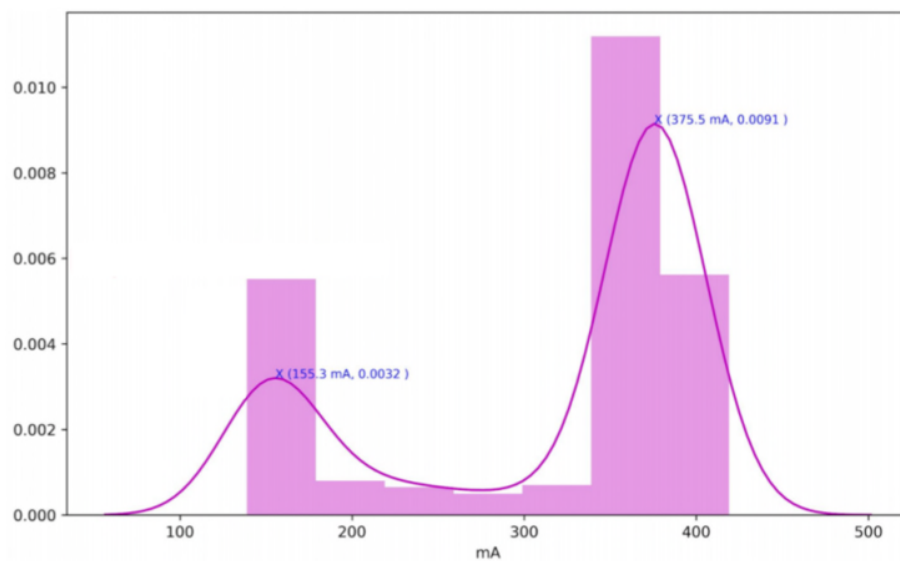


**Fig. 4: Example current waveforms captured by the power supply. The blue circles are current samples. (a) Raw current waveforms; (b) Current waveform after processing to remove peak artifacts.**

### Measuring the average current

As explained earlier, the duty cycle can be computed, using equation (1), in terms of the low, high, and average currents. The average current is simply computed as the arithmetic mean of the artifact-free current samples generated by the power supply.

### Measuring low and high currents

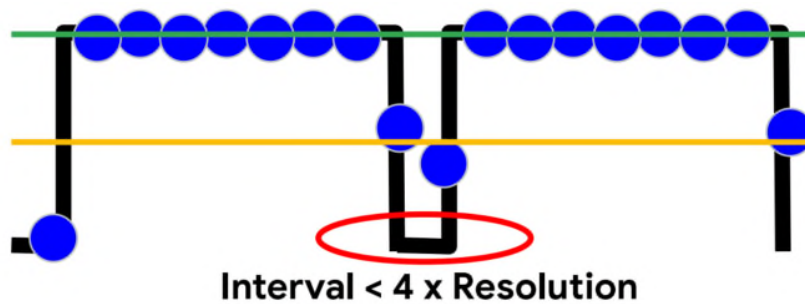


**Fig. 5: Histogram of current samples**

To measure the low and the high current values, a histogram of current samples is constructed, as illustrated in Fig. 5. Since the current waveform is essentially binary-valued, e.g., takes on principally two values, the histogram is bi-modal, e.g., has two maxima. The low-current value is read as the histogram maximum that occurs at the lower abscissa. The high-current value is read as the histogram maximum that occurs at the higher abscissa.

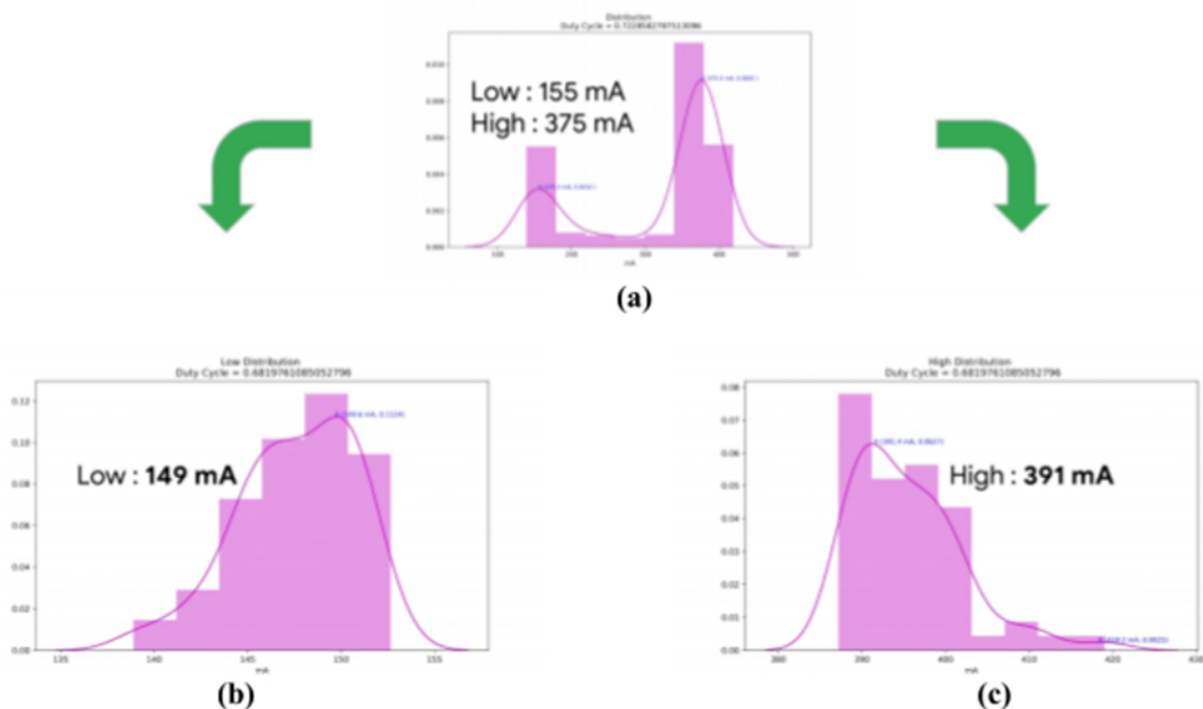
Although the above technique produces reasonably accurate estimates for the low and the high currents, the estimates can be contaminated by samples captured during low-to-high or high-to-low transitions.





**Fig. 6: Low-to-high or high-to-low transitions produce samples that are neither low nor high**

This is illustrated in Fig. 6, where the Tx-off time (red oval) is so narrow (less than sampling resolution) that no samples are captured during that time, and the only samples captured are those on the low-to-high and the high-to-low transitions. The estimates of low and high currents are especially vulnerable to contamination if the Tx-on time is narrow (e.g., very high duty cycle) or if the Tx-off time is narrow (e.g., very low duty cycle).

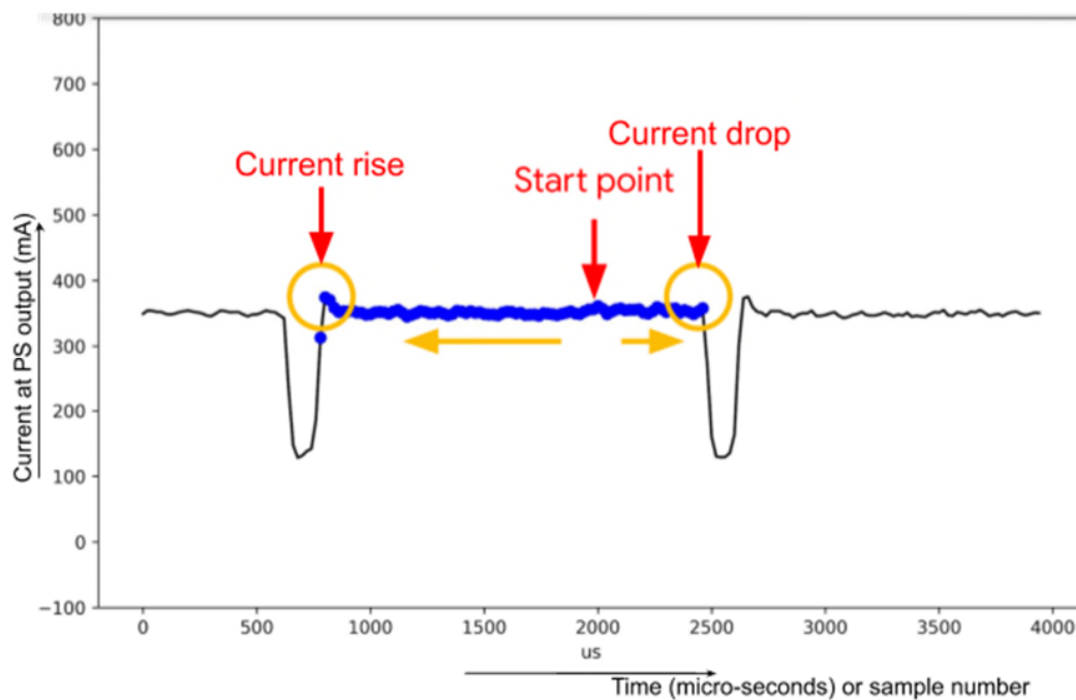


**Fig. 7: Estimating low and high currents robustly**

Fig. 7 illustrates the robust estimation of low and high currents, e.g., applicable to situations of very high or very low duty cycle. A band of current samples around the midpoint of the two maxima of the current histogram is rejected (Fig. 7(a)). A *lower* histogram is formed of values between zero and the midpoint (Fig. 7(b)). A *higher* histogram is formed of values between the midpoint and the maximum observed current (Fig. 7(c)). The low current is estimated as the peak of the lower histogram. The high current is estimated as the peak of the higher histogram.

With the measurement of the low, high, and average currents completed as described above, the duty cycle is computed in accordance with equation (1).

#### Measuring transmitter on-time



**Fig. 8: Estimating transmitter on-time**

Fig. 8 illustrates using the current at the output of the power supply to determine the on-time of an electronic device, e.g., a WiFi transmitter. On-time is signaled by a jump in current

consumed, and off-time is signaled by a drop in current consumed. The techniques measure the number of samples between a sharp rise in current and a sharp drop in current, and multiply it by the resolution of the current sampler:

$$T_{\text{X on}} = (\text{Current rise sample-number} - \text{Current drop sample-number}) \times \text{Resolution}$$

The techniques of this disclosure achieve, across a broad range of scenarios, accurate measurements (error rate < 5%) of duty-cycle and transmitter on-time. The principal apparatus needed for the measurements is a power supply, the cost of which is ten-to-twenty percent of the cost of conventional measurement equipment such as digital oscilloscopes or spectrum analyzers.

## CONCLUSION

This disclosure describes techniques that leverage the ability of a power supply to sample a current supplied by it to a device under test (DUT) to determine the duty cycle and the on-time of the DUT. The techniques of this disclosure achieve, across a broad range of scenarios, accurate measurements of duty-cycle and transmitter on-time. The cost of the measurement apparatus is significantly lower than the cost of conventional measurement equipment such as digital oscilloscopes or spectrum analyzers.